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Effects of the COVID-19 Pandemic Lockdown on the Quality and Pollution of Irrigation Water in the Dams of Jordan

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Abstract: While the world continues to tackle the COVID-19 pandemic and its impacts on public health and the economy, among other issues (e.g., the environment), water, as a major component of the environment, has been significantly affected. This research aims to examine the quality and pollution of irrigation water in six selected vital dams in Jordan, in terms of the Irrigation Water Quality Index (IWQI) and Irrigation Water Pollution Index (IWPI), respectively, in view of determining any changes in the water quality and pollution load between the COVID-19 lockdown and the pre-COVID-19 period. The results of this study revealed that all of the studied dams showed an improvement in the quality of irrigation water and a reduction in pollution levels during the COVID-19 lockdown. This was due to a decrease in industrial, anthropogenic, urban, and agricultural activities, and strict restrictions on mobility and transportation. The improvement percentage in the irrigation water quality during the lockdown based on the IWQI model was in the following order: King Talal dam > Al-Kafrein dam > Al-Wehdeh dam > Kufranja dam > Wadi Al-Arab dam > Zeqlab dam, which is similar to the order of the reduction percentage in pollution based on the IWPI model. Therefore, the results of the IWPI model are consistent with those of the IWQI model. The classification of irrigation water based on the IWQI values indicated that the irrigation water quality of Al-Wehdeh and King Talal dams changed to better categories during the lockdown. All values of physicochemical and biological parameters in the dams' water were within the Jordanian and international (FAO) standard limits for irrigation, except for the Na concentrations in some dams that were above the FAO standards.

Keywords: COVID-19; lockdown; irrigation water quality index (IWQI); irrigation water pollution index (IWPI); dams in Jordan

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1. Introduction

In Jordan, alarm bells ring, bringing distressful news about the scarcity of water. With limited water resources, Jordan is the second water-poorest country in the world. Its annual renewable water per capita is less than 100 cubic meters, well below the international severe water scarcity threshold of 500 cubic meters per capita [1]. Consequently, the country faces complex development challenges, since water resources are essential for municipal, domestic, agricultural, and industrial uses. Water is therefore among the most important pillars of Jordan's economic and social development. Jordan's water scarcity is exacerbated by its rising population, economic growth, degrading climatic conditions (decreasing rainfall rates and increasing temperature), a significant increase in the number of refugees due to the political and security situation in neighboring countries, and the COVID-19 pandemic-induced conditions of life. The aforementioned factors are likely to threaten the ability of Jordanian citizens to access potable water in the coming years [2].

Induced by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), COVID-19 is an ongoing pandemic [3] that has left tremendous impacts on the environment and its components. As a vital component of the environment, water has been impacted by this pandemic [4,5]. On 30 January 2020, the World Health Organization (WHO) declared the

rapid COVID-19 outbreak as an international public health emergency [5]. Jordan's government declared the country's first confirmed COVID-19 case on 2 March 2020. Subsequently, COVID-19 spread rapidly in Jordan. Most countries, including Jordan, imposed general lockdowns to avoid the spread of the coronavirus. Following these lockdowns, the water deficit in Jordan has grown as the water demand has recently increased; Jordan's water deficit reached 40 million cubic meters (MCM) in 2021 [6]. The Jordan government has made considerable efforts to address and manage water deficit issues by developing and adopting several strategies. These include executing water harvesting projects (constructing dams), enhancing water use efficiency, reducing water losses, lowering and controlling groundwater over-extraction, and expanding and improving wastewater services, especially during the pandemic conditions of COVID-19 [2,7].

The main resources that supply water in Jordan are groundwater, at about 59%; surface water, at about 27%; and treated sewage, at about 14% [1]. Dams are among the most important surface water sources in Jordan; their water is used for domestic, agricultural, and industrial purposes. All of the dams together provide around 308 MCM of the country's water needs, while the country's total need was approximately 1412 MCM in the year 2017 [1]. In June 2022, the total amount of water stored in Jordan's dams was recorded as 27% (~75 MCM) of their total storage capacity, which puts the country in a critical situation concerning its increasing water demand and scarce water supply [6]. In this context, finding alternative sources of water to fill the supply/demand gap in Jordan is no less important than protecting Jordan's limited water sources from pollution and maintaining the optimal water quality for any intended uses. The water usage of Jordan's dams is governed by their water quality; therefore, it is necessary to protect the dams' water from all sources of pollution in order to preserve the aquatic ecosystem and ensure the optimal use of the water. Jordan's dams are exposed to many sources of pollution caused by industrial, agricultural, and urban activities, leading to the deterioration of their water quality [8,9]. Consequently, we must continue to conduct research on the assessment of surface water quality, particularly dam water. Furthermore, sources of pollution should be identified and monitored. Hence, this study is significant, as the study's outcomes could be helpful to, and important for, decision-makers and relevant institutions to develop appropriate and systematic approaches for the optimal management and monitoring of water and pollution resources. Decisions taken by officials on water issues play an effective role in the protection of the environment and water sources against pollution, with positive implications for the economic and health aspects of the citizens.

Several worldwide studies have been conducted to analyze the effects of the COVID-19 pandemic on the environment, particularly on water. Indeed, the side effects of the pandemic on water and the water environment can be both negative and positive [10]. Numerous recent studies have examined the positive impacts of the COVID-19 lockdown on the quality of surface water. These studies have demonstrated that surface water quality has improved, and pollution levels have reduced remarkably during the lockdown [10–13]. For instance, Pant et al. [14] analyzed the quality of the surface water in a river basin in Nepal during the lockdown and found a positive recovery in the water quality. Similar findings on rivers and lakes in Malaysia presented significant improvements in the water quality and water quality index (WQI) during the lockdown [15]. Regarding the water quality and pollution parameters of a river in Delhi, Patel et al. [16] showed that the WQI increased by 37% during the lockdown period, and that pollution parameters decreased considerably. Other studies on the Ganga river (India) demonstrated a significant improvement in river water quality during the lockdown period [17,18]. In contrast, few studies have examined the effects of the COVID-19-induced lockdown on the aquatic environment; these studies have shown improvements in the aquatic ecosystem and biodiversity [19,20]. Nevertheless, further studies are required to examine the effects of COVID-19 on aquatic ecosystems and their interactions.

On the contrary, several studies have shed light on the negative effects of the COVID-19 lockdown on the water sector of a nation. For example, Sayeed et al. [21] estimated the over-

consumption of water in Bangladesh during the pandemic and revealed an increase in home water consumption during the lockdown, particularly for handwashing purposes. A similar study [22] also showed that lifestyle changes during the pandemic caused a significant increase in household water consumption, mainly in the southern and eastern parts of England. Moreover, Li et al. [23] investigated water uses in California, U.S., since the start of the pandemic and during the lockdowns. They showed a reduction of 7.9% in urban water use due to the restrictions imposed on different sectors (e.g., industrial and commercial). In contrast, there was an increase of 1.4% in domestic water use. Importantly, the medications used to cure COVID-19, and the preventive measures adopted to prevent the pandemic's outbreak, can produce wastes and chemicals which are regarded as emerging pollutants that are harmful to the aquatic environment and can contaminate water resources [20,24,25].

This research will be the first in Jordan so far to focus on the quality and pollution of dams' water during the lockdown of COVID-19. It sheds light on the impacts of anthropogenic activities on the dams' water quality, taking advantage of the shutdown of these activities in the country during the COVID-19 lockdown. Two different models are used in the present study to evaluate the water quality and pollution of dams in Jordan.

This study aims to: (1) examine the quality and pollution of irrigation water in six selected vital dams of Jordan in terms of the irrigation water quality index (IWQI) and irrigation water pollution index (IWPI), with a view to determining any changes in the water quality and pollution load between the COVID-19 lockdown and the pre-COVID-19 period; and (2) highlight the impacts of anthropogenic activities on dams' water pollution and quality by comparing water quality and pollution in the pre-COVID-19 period, that is, during the normal state of human activities and during the COVID-19 lockdown, when most human activities were suspended.

2. Data and Methodology

2.1. Dams in Jordan

There are currently 14 dams in Jordan used for domestic, municipal, and agricultural purposes. This study focused on six vital dams in Jordan (Al-Wehdeh, King Talal, Wadi Al-Arab, Al-Kafrein, Zeqlab, and Kufranja dams) (Figure 1) to identify the impacts of the COVID-19-induced lockdown on the Irrigation Water Quality Index (IWQI) and Irrigation Water Pollution Index (IWPI) of these dams. Some of the dams in Jordan, particularly in its southern areas (e.g., Al-Tanoor dam, Al-Mujib dam, Wadi Shuaib dam, and Al-Wala dam), were not selected for this study because they are exposed to drought each year (this is true particularly for 2021 and 2022) [6]. Therefore, it is not feasible to investigate the changes in their water qualities.

The information pertaining to the location of dams, year of operation, capacity, types, major tributaries, watersheds, and water use are presented and summarized in Table 1.

Table 1. Summarized information about the selected dams in this study [26–28].

Name of Dam	Location and City	Year of Operation	Capacity (MCM)	Type	Major Tributary/Major Basin	Catchment Area km^2	Usage	Average Storage (MCM) in 2019	Total Inflow (MCM) in 2019	Usage Amount (MCM) in 2019
Al-Wehdeh Dam	Northern highland of Jordan/Yarmouk district-Irbid City	2006	110	Roller Compacted Concrete (RCC).	Yarmouk river/Yarmouk basin	5590 km^2, out of which 1200 km^2 on the Jordanian side.	Irrigation, municipal, and industrial.	32.32	54.02	60.33
King Talal Dam	Northwest of Jordan—Jerash City	1977 Enlarged in 1987	75	Earth and Rock-Fill	Zarqa river/Zarqa basin	3700	Irrigation and electrical generation	74.62	152.7	147.65
Wadi Al-Arab Dam	Jordan Valley-Irbid City	1986	16.79	Earth Fill	Wadi Al-Arab/North Rift Side Wadis basin	262	Irrigation, municipal, industrial, and electrical generation	9.95	9.91	9.91

Table 1. *Cont.*

Name of Dam	Location and City	Year of Operation	Capacity (MCM)	Type	Major Tributary/Major Basin	Catchment Area km^2	Usage	Average Storage (MCM) in 2019	Total Inflow (MCM) in 2019	Usage Amount (MCM) in 2019
Al-Kafrein Dam	Jordan Valley-Al-Balqa City	1968 Extended in 1997	8.45	Earth Fill	Wadi Al-Kafrein/South Rift Side Wadis basin	163	Irrigation, and recharge	7.8	14.62	14.32
Kufranja Dam	Ajloun City	2017	7.8	Concrete-Face Rock-Fill dam (CFRD)	Wadi Kufranja /North Rift Side Wadis basin	99	Irrigation, municipal, and recharge	7.41	11.8	10.26
Zeqlab Dam	Jordan Valley-Irbid City	1964	3.96	Earth Fill	Wadi Zeglab/North Rift Side Wadis basin	106	Irrigation, municipal, and industrial	0.92	0.59	0.67

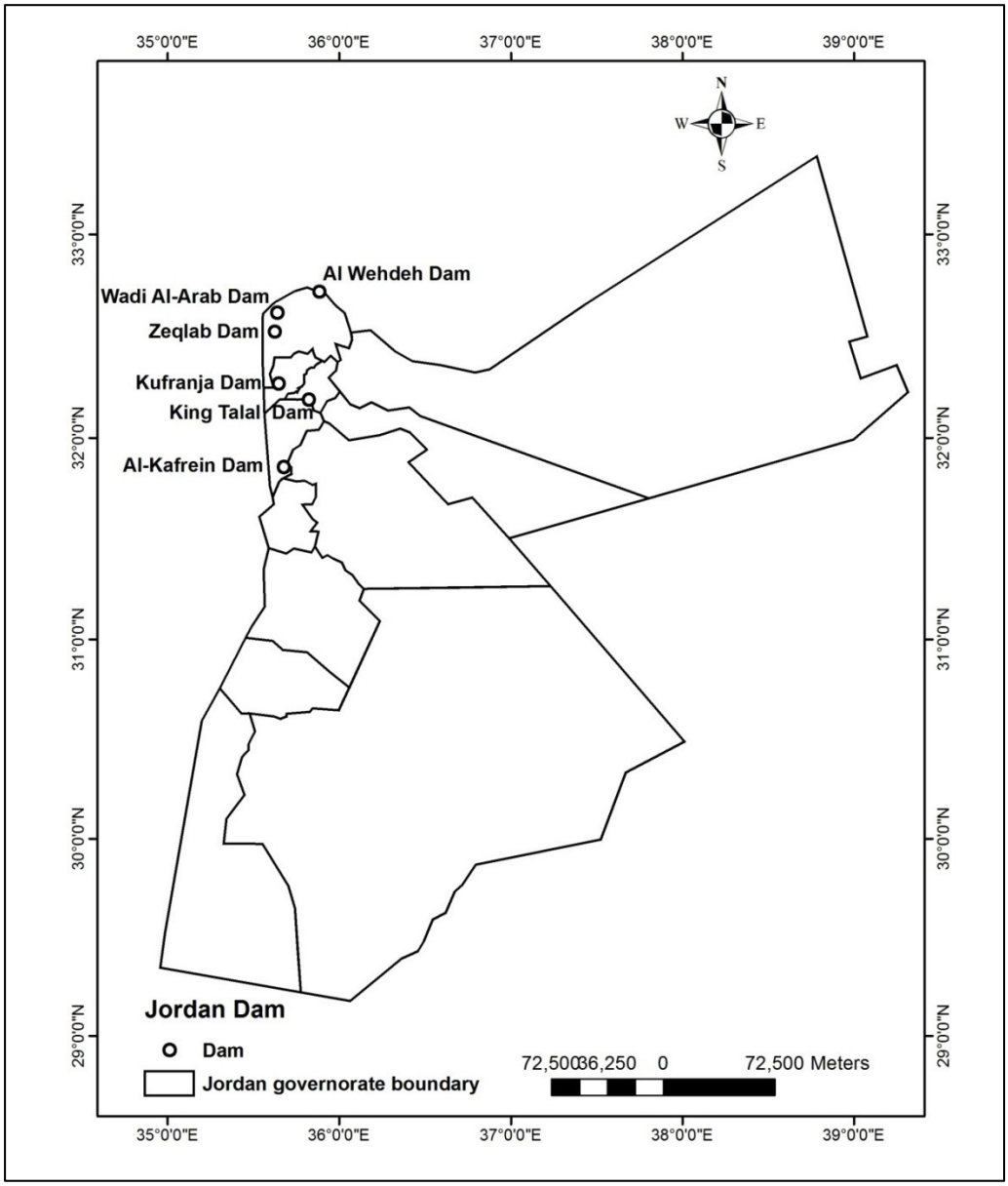


Figure 1. Location map of the studied dams.

2.2. The Dataset of the Physicochemical and Biological Parameters in the Water of the Studied Dams in Jordan

We selected a total of 12 physicochemical and biological parameters to perform this study: hydrogen ion concentration—pH, electrical conductivity—EC (µs/cm), total dissolved solids—TDS (mg/L), total suspended solids—TSS (mg/L), Sodium—Na^+ (mg/L), Magnesium—Mg^{2+} (mg/L), Calcium—Ca^{2+} (mg/L), Sodium absorption ratio—SAR, chloride—Cl^- (mg/L), Nitrates—$NO_3{}^-$ (mg/L), bicarbonate—$HCO_3{}^-$ (mg/L), and *Escherichia coli—E. coli*. The dataset regarding the abovementioned parameters of the studied dams was obtained from Jordan's Ministry of the Environment (MoE) (Jordan's National Water Quality Monitoring Project) [27,28], excluding the pre-COVID-19 data on the Kufranja dam for 2019, which was obtained from the project investigating the water quality of the Kufranja dam, funded by the Deanship of Scientific Research at the University of Jordan, Jordan [(No. 2202), PI: Dr. Mahmoud Abualhaija]. Specifically, this study used the dataset containing all the water quality parameters recorded for a specific period during the 2020 lockdown, along with the dataset for the same timespan in 2019, before the lockdown. According to the reports of the Ministry of Environment [27,28] and the Kufranja dam water quality project, the studied dams' water samples were collected from the dams' outlet points and analyzed based on the Standard Methods for the Examination of Water and Wastewater [29].

2.3. Calculation of the Irrigation Water Quality Index (IWQI)

Numerous water quality indices have been developed and applied to determine the relevance of water for different uses, particularly for drinking and irrigation [30–40]. In this study, the irrigation water quality index (IWQI) was calculated based on the specified model developed by Meireles et al. [30], that was used to evaluate agricultural water quality. The IWQI was calculated according to the following two main steps. The first step comprised the identification of the vital physicochemical parameters that play a significant role in water quality for irrigation; five water quality parameters were adopted, including electrical conductivity (EC), sodium absorption ratio (SAR), sodium (Na^+), chloride (Cl^-), and bicarbonate ($HCO_3{}^-$). The second step involved the determination of the water quality measurement value (Qi) and the accumulation weights (Wi) for each parameter. The value of (Qi) was figured based on the experimental value of each parameter and on the irrigation water quality parameters published by the University of California Committee of Consultants—(UCCC) and complying with the standards published by Ayers and Westcot (1999) as described in Table 2. The parameters of the water quality have been expressed by non-dimensional numbers, where the highest value corresponded to the best water quality [30].

Table 2. Parameter limiting values for quality measurement (Qi) calculation [30].

Qi	EC µs/cm	SAR	Na^- meq/L	Cl^- meq/L	$HCO_3{}^-$ meq/L
85–100	$200 \leq EC < 750$	$2 \leq SAR < 3$	$2 \leq Na < 3$	$1 \leq Cl < 4$	$1 \leq HCO_3 < 1.5$
60–85	$750 \leq EC < 1500$	$3 \leq SAR < 6$	$3 \leq Na < 6$	$4 \leq Cl < 7$	$1.5 \leq HCO_3 < 4.5$
35–60	$1500 \leq EC < 3000$	$6 \leq SAR < 12$	$6 \leq Na < 9$	$7 \leq Cl < 10$	$4.5 \leq HCO_3 < 8.5$
0–35	$EC < 200$ or $EC \geq 3000$	$SAR < 2$ or $SAR \geq 12$	$Na < 2$ or $Na \geq 9$	$Cl < 1$ or $Cl \geq 10$	$HCO_3 < 1$ or $HCO_3 \geq 8.5$

Qi values were computed using Equation (1) and from the tolerance limits presented in Table 2, and from the experimental results of the analyzed parameters.

$$Qi = Q_{imax} - \left[\left(X_{ij} - X_{inf} \right) \times Q_{iamp} \right) / X_{amp}] \quad (1)$$

where, Q_{imax} represents the maximum Qi value for the class; X_{ij} is the experimental or monitored value of each parameter. X_{inf} is the value that corresponds to the bottom limit of the class to which the parameter belongs; Q_{iamp} refers to the class amplitude; where the range of class (class amplitude) to which the parameter corresponds is represented by

X_{amp}. To determine the X_{amp} value of the latter class of each parameter, the upper bound of the relevant class was considered as the maximum value obtained from the experimental analysis of the water samples [30].

The accumulation weight (Wi) values for the parameters used in the IWQI calculation were taken from [30] (Table 3), where Wi values have been normalized and their sum equals one.

Table 3. Weights for the IWQI parameters [30].

Parameter	Weight (Wi)
EC	0.211
Na^+	0.204
HCO_3^-	0.202
Cl^-	0.194
SAR	0.189
Total	1.000

IWQI was computed as the following formula (Equation (2)).

$$IWQI = \sum_{i=1}^{n} Qi \times Wi \quad (2)$$

IWQI is an index that has no dimension, ranging from 0 to 100; Qi describes the quality of the ith parameter, a function of its measurement or concentration; Wi is the normalized weight of the ith parameter, a function of its relative importance in irrigation water quality [30].

2.4. Calculation of the Irrigation Water Pollution Index (IWPI)

The model used for the calculation of the water pollution index (WPI) was developed by Hossain and Patra [41]. In this research, WPI was used to determine the water pollution index of the dams in Jordan for irrigation purposes. It is based on the recommended standard limits for irrigation uses published by the Jordan Institution for Standards and Metrology (JSMO) [42] and Food and Agriculture Organizations (FAO) [43], and is therefore named the irrigation water pollution index (IWPI).

A total of 12 physicochemical and biological parameters, including pH, EC, TDS, TSS, Na^+, Mg^{2+}, Ca^{2+}, SAR, Cl^-, NO_3^-, HCO_3^-, and *E. coli*, were used in the calculation of the IWPI based on their standard permissible limits for irrigation purposes. The IWPI was calculated based on two steps: the first is to calculate the pollution load of each parameter, whereas the second is to aggregate the pollution load of all parameters and divide the sum by the number of all parameters included [41].

The pollution load (PLi) is computed using the following formula (Equation (3)):

$$PLi = 1 + \left(\frac{Ci - Si}{Si}\right) \quad (3)$$

where Ci is the monitored or observed concentration of the ith parameter, Si represents the standard or maximum acceptable limit for the individual parameter based on the standard limits for irrigation purposes. The calculation of PLi for the pH has a particular case; if the value of pH is less than 7, then the following equation (Equation (4)) is recommended to calculate the PLi [41], where Si_a is the minimum acceptable pH for irrigation use.

$$PLi = \frac{Ci - 7}{Si_a - 7} \quad (4)$$

whereas Equation (5) is suggested to compute the PLi when the pH value is greater than 7, where Si_b represents the maximum permissible pH for irrigation use.

$$PLi = \frac{Ci - 7}{Si_b - 7} \quad (5)$$

Finally, the IWPI was computed using the formula below (Equation (6)):

$$IWPI = \frac{1}{n} \sum_{i=1}^{n} PLi \quad (6)$$

where (n) refers to the number of parameters involved.

There are four categories for the classification of IWPI [41] as follows: when IWPI < 0.5, the water quality is excellent; the water quality is good if IWPI is between 0.5 to 0.75; the water is moderately polluted if it varies from 0.75 to 1; and the water is highly polluted when IWPI > 1.

3. Results and Discussions

3.1. Water Quality Parameters

Most water quality parameters have revealed a decrease in their concentrations during the COVID-19-induced lockdown, as compared to their concentrations in the same time period in the previous year before the start of the pandemic (Figure 2). This finding can be ascribed to the shutdown of industrial and human activities and the slowdown of the agricultural and urban runoff, in addition to high restrictions on transportation and mobility. This lead to a considerable decrease in the pollutant and other waste discharges to the surface water bodies and facilitated the betterment of water quality [11,15,44–46].

All physicochemical and biological parameter values in the studied dams (pH, EC, TDS, TSS, Na^+, Mg^{2+}, Ca^{2+}, SAR, Cl^-, $NO_3{}^-$, $HCO_3{}^-$, and *E.coli*) (Table 4) were within the Jordanian [42] and FAO [43] standard limits for irrigation, except the Na concentrations for the King Talal dam (pre- COVID-19 and during lockdown) and Al-Wehdeh and Al-Kafrein dams (before COVID-19), which were above the FAO irrigation standards [43].

Table 4. Results of water quality parameters of the selected dams in Jordan [27,28].

Pre-COVID-19 (2019)												
Dam	**pH (SU)**	**EC (µs/cm)**	**TDS (mg/L)**	**TSS (mg/L)**	**Na^- (mg/L)**	**Mg^{2+} (mg/L)**	**Ca^{2+} (mg/L)**	**SAR**	**Cl^- (mg/L)**	**$NO_3{}^-$ (mg/L)**	**$HCO_3{}^-$ (mg/L)**	***E. coli***
Al-Wehdeh Dam	8.44	883	502	12.0	83.1	31.3	62.5	1.99	99.0	2.1	229	11
King Talal Dam	8.34	1610	920	11.8	171	27.8	89.8	4.04	269	28.9	271	17
Wadi Al-Arab Dam	8.74	769	418	10.3	68.9	24.1	39.3	2.14	113	7.4	145	63.5
Al-Kafrein Dam	8.89	805	447	39.3	70.3	28.6	32.8	2.17	114	15.6	85.0	130
Zeqlab Dam	8.33	850	476	8.30	35.1	43.3	64.1	0.83	59.8	1.0	308	19.5
Kufranja Dam	7.90	751	466	5.00	29.7	28.5	54.0	0.81	70.5	31.6	225	8.7
Min	7.90	751	418	5.00	29.7	24.1	32.8	0.81	59.8	1.0	85.0	8.7
Max	8.89	1610	920	39.3	171	43.3	89.8	4.04	269	31.6	308	130
Mean	8.44	945	538	14.4	76.3	30.6	57.1	2.00	120.8	14.4	210	41.6
During the COVID-19 lockdown (2020)												
Dam	**pH (SU)**	**EC (µs/cm)**	**TDS (mg/L)**	**TSS (mg/L)**	**Na^- (mg/L)**	**Mg^{2+} (mg/L)**	**Ca^{2+} (mg/L)**	**SAR**	**Cl^- (mg/L)**	**$NO_3{}^-$ (mg/L)**	**$HCO_3{}^-$ (mg/L)**	***E. coli***
Al-Wehdeh Dam	8.31	862	495	9.0	66.2	25.1	68.8	1.74	90.6	1.0	247	1.8
King Talal Dam	8.25	1380	753	2.0	148	24.9	82.1	3.67	219	38	243	13
Wadi Al-Arab Dam	9.01	690	360	38	66.7	20.4	35.5	2.21	109	3.9	108	13
Al-Kafrein Dam	9.26	682	361	12	62.7	26.3	30.3	2.01	106	35.6	57.2	4.0
Zeqlab Dam	8.41	755	370	15	37.4	38.4	63.3	0.91	58.6	1.0	279	79
Kufranja Dam	7.84	611	292	3.0	28.9	23.2	54.0	0.80	69.5	27.7	172	4.5
Min	7.84	611	292	2.0	28.9	20.4	30.3	0.80	58.6	1.0	57.2	1.8
Max	9.26	1380	753	38.0	148	38.4	82.1	3.67	219	38	279	79
Mean	8.51	830	439	13.2	68.3	26.4	55.7	1.89	108.8	17.9	184.4	19.2

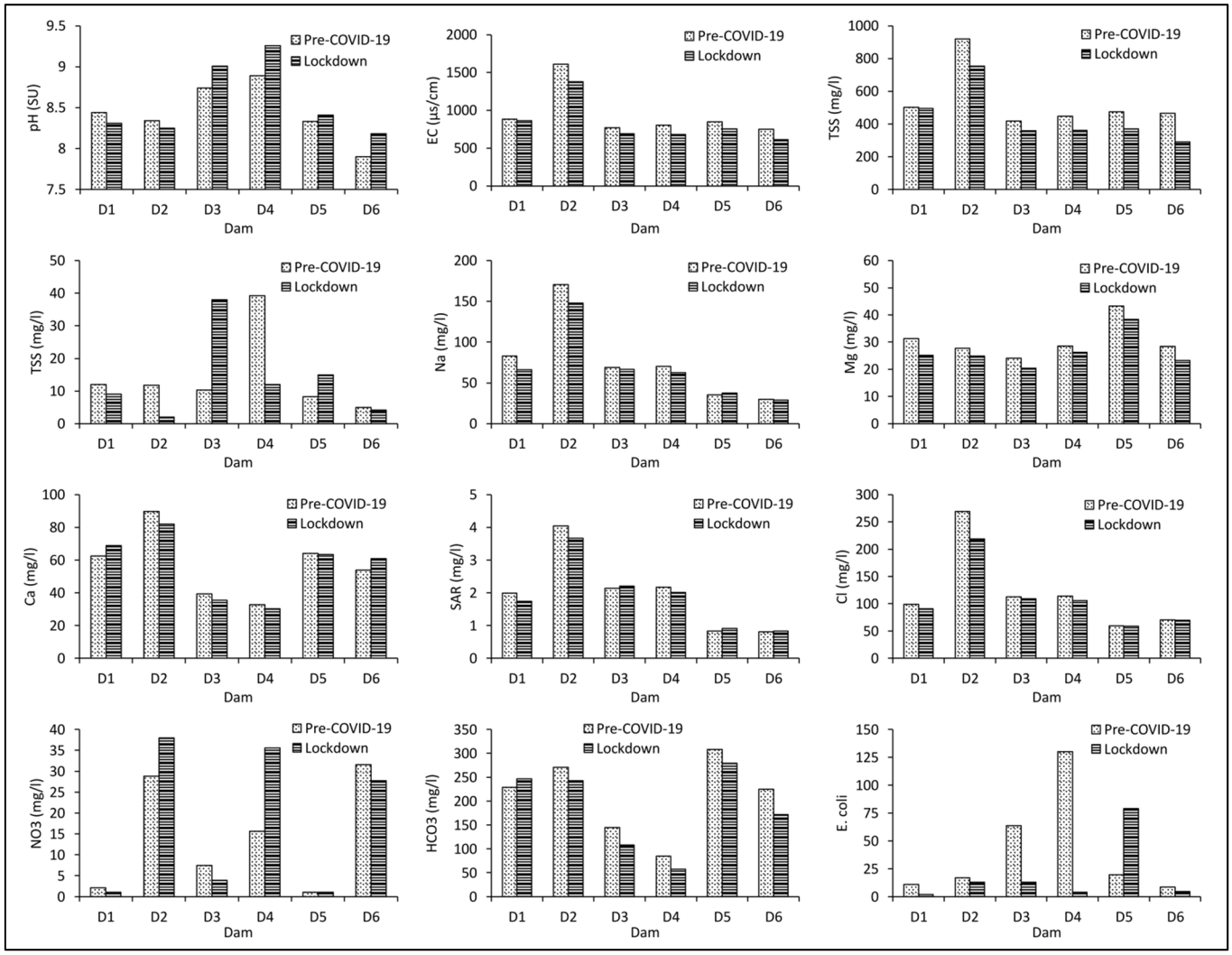


Figure 2. Physicochemical and biological parameters in the dams' water of Jordan pre-COVID-19 and during the lockdown (D1: Al-Wehdeh dam, D2: King Talal dam, D3: Wadi Al-Arab dam, D4: Al-Kafrein dam, D5: Zeqlab dam and D6: Kufranja dam).

3.2. Irrigation Water Quality Index (IWQI) and Irrigation Water Pollution Index (IWPI)

The results of IWQI using the adopted model by Meireles et al. [30] (Table 5) and the classifications of water quality based on IWQI values (Table 6) showed that the IWQI values of Al-Wehdeh Dam belonged to the moderate restriction (MR) category for irrigation pre-COVID-19 and changed to the low restriction (LR) category during the COVID-19 lockdown.

Table 5. IWQI values of the dams in Jordan before the start of COVID-19 and during the lockdown period.

Dam	IWQI Pre-COVID-19	IWQI during the Lockdown
Al-Wehdeh Dam	69.5	72.2
King Talal Dam	54.4	60.9
Wadi Al-Arab Dam	86.7	88.3
Al-Kafrein Dam	88.3	93.4
Zeqlab Dam	61.4	62.5
Kufranja Dam	63.8	66.0
Min	54.4	60.9
Max	88.3	93.4
Mean	70.7	73.9

Table 6. Characteristics of the IWQI [30].

IWQI	Water use Restrictions	Recommendation and Uses	
85–100	No restriction (NR)	May be used for the majority of soils with low probability of causing salinity and sodicity problems, being recommended for leaching within irrigation practices, except for in soils with extremely low permeability.	No toxicity risk for most plants
70–85	Low restriction (LR)	Recommended for use in irrigated soils with light texture or moderate permeability, being recommended for salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay.	Avoid salt sensitive plants
55–70	Moderate restriction (MR)	May be used in soils with moderate to high permeability values, being suggested for moderate leaching of salts.	Plants with moderate tolerance to salts may be grown
40–55	High restriction (HR)	May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 µs/cm and SAR above 7.0.	Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except for water with low Na, Cl, and HCO_3 values.
0–40	Severe restriction (SR)	Should be avoided for irrigation use under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR requires gypsum application. In high saline content water soils must have high permeability, and excess water should be applied to avoid salt accumulation.	Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl, and HCO_3.

The IWQI of King Talal Dam before the onset of COVID-19 fell under the category of high restriction (HR). However, with the imposition of the lockdown, its water quality changed to a moderate restriction (MR) category for irrigation. The IWQI values for the Wadi Al-Arab and Al-Kafrein dams fell in the no restriction (NR) category for irrigation for the pre-COVID-19 period as well the lockdown period. In contrast, the values of IWQI for the Zeqlab and Kufranja dams were categorized as requiring a moderate restriction (MR) for irrigation pre-COVID-19 and also during the lockdown. The categorizations of irrigation water based on the values of IWQI, in addition to the concomitant recommendations and suitable uses, are illustrated in Table 6.

The results of IWPI using Equation (6) [41] (Table 7) and the water quality classifications according to IWPI values revealed that the values of IWPI in the examined dams pre-COVID-19 and during the lockdown fell under the category of "excellent for irrigation". An exception was the IWPI value of King Talal dam, that fell under the category of "good for irrigation" pre-COVID-19 and changed to the category of "excellent for irrigation" during the lockdown.

The results of water quality represented by IWQI and the pollution load specified by the IWPI (Figures 3 and 4; Tables 5 and 7) demonstrated that the irrigation water quality of the dams in Jordan had improved during the COVID-19-induced lockdown, thanks to an observed increase in the IWQI values and a decrease in the values of IWPI during the COVID-19 lockdown compared to the pre-COVID-19 period. The lockdown-induced high restrictions on many sectors and activities led to an interruption or decrease

in the flow of industrial effluents and other kinds of waste to the surface water, which improved its water quality and reduced its pollution load [13,46,47]. This underscores the important role of anthropogenic activities in surface water quality changes and degradation. Consequently, immediate actions are required to reduce anthropogenic activities and their negative impacts on the environment.

Table 7. IWPI values of the dams in Jordan pre-COVID-19 and during the lockdown period.

Dam	IWPI Pre-COVID-19	IWPI during Lockdown
Al-Wehdeh Dam	0.278	0.257
King Talal Dam	0.505	0.446
Wadi Al-Arab Dam	0.261	0.260
Al-Kafrein Dam	0.297	0.272
Zeqlab Dam	0.252	0.252
Kufranja Dam	0.218	0.204
Min	0.218	0.204
Max	0.505	0.446
Mean	0.302	0.282

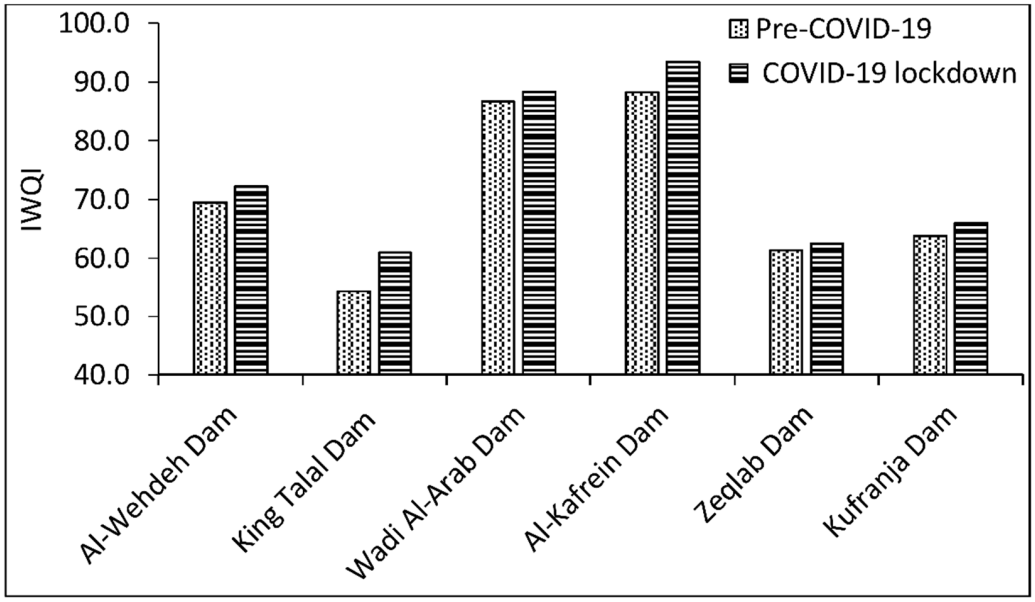


Figure 3. IWQI value of the dams pre-COVID-19 and during the lockdown period of the pandemic.

In the lockdown period, the largest percentage of improvement in IWQI, 10.67%, was noticed for King Talal dam followed by Al-Kafrein dam (5.46%), Al-Wehdeh dam (3.74%), Kufranja dam (3.19%), Wadi Al-Arab dam (1.81%), and Zeqlab dam (1.76%). The respective reduction percentages in the IWPI values during the lockdown arranged the dams in the following order: King Talal Dam (11.5%) > Al-Kafrein Dam (8.7%), Al-Wehdeh Dam (7.7%) > Kufranja Dam (6.3%) > Wadi Al-Arab Dam (0.4%) > Zeqlab Dam (0.3%). This arrangement was identical to the aforementioned order of improvement in the irrigation water quality of the dams studied (based on the IWQI model). Therefore, the IWPI model results were consistent with the IWQI model results.

King Talal dam recorded the highest improvement percentage regarding water quality and the highest reduction in the pollution load during the lockdown (Figures 3 and 4). Compared to the other dams in Jordan, King Talal dam indeed has the largest catchment area, total storage, total inflow, and total usage (Table 1), and its main tributary (Zarqa River) is located in the Zarqa River Basin (ZRB). ZRB is considered one of Jordan's most important basins in terms of its economic, social, and agricultural importance; it has an

estimated area of 4120 km^2 from its upper northern point to its outlet, near the King Talal dam. Moreover, ZRB hosts more than 50% of Jordan's population and is the hub of the majority of its industrial, agricultural and other anthropogenic activities [32,48,49]. In this light, one can explain the significant recovery in King Talal dam's water quality during the lockdown period, where most activities were stopped, including industrial and human activities. On the other hand, Zeglab dam achieved the lowest improvement percentage regarding water quality and the lowest reduction percentage in terms of its pollution load, which may be attributed to the small catchment area of the dam compared to the other dams studied (Table 1). Besides, Zeglab dam hosts fairly fewer industrial and anthropogenic operations.

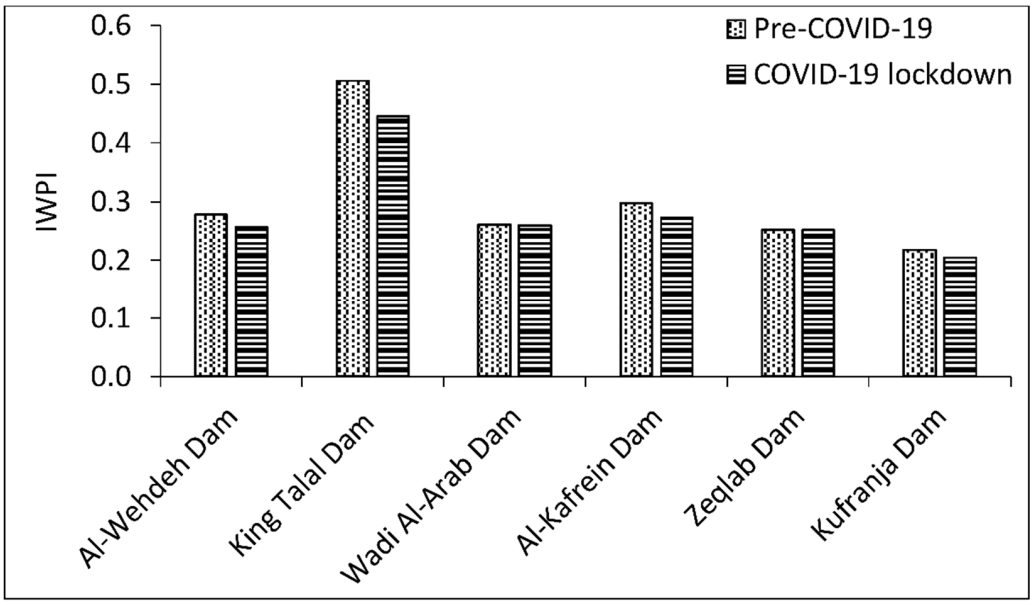


Figure 4. IWPI value of the studied dams before COVID-19 and during the lockdown period.

The improvement in the water quality of the dams in Jordan during the lockdown period can be ascribed to the shutdown of industrial and anthropogenic activities along with urban and agricultural runoff, in addition to the constraints on transportation and mobility, which led to a considerable decrease in air pollution and thus a reduction in the level of water pollution [50]. This indicates that anthropogenic factors significantly affect the environment and are to blame for the deterioration of the dams' water quality. Therefore, water resources, anthropogenic activities and pollution sources must be effectively managed, tracked, and monitored. Finally, the results of this research are in line with the results of several recent studies that have previously confirmed noticeable improvements and a recovery in the surface water quality of various nations during the COVID-19-induced lockdown [11,13–18,51].

4. Conclusions

This paper focuses on the impacts of the COVID-19-induced lockdown on the quality and pollution of irrigation water of Jordan's dams. Two different models are adopted in this study to determine the changes in the irrigation water quality and pollution load between the COVID-19-induced lockdown phase and the pre-COVID-19 period.

All the studied dams in this research show improvement regarding water quality and decreases in water pollution during the lockdown. This is evidenced by the increases in the relevant IWQI values and decreases in the involved IWPI values; this scenario can be attributed to a significant decrease in industrial, urban, and agricultural activities, as well as the high restrictions on movement and transportation during the lockdown period. Therefore, detailed studies are needed to assess the effects of human, industrial,

and agricultural activities on a nation's water quality and water pollution levels. Moreover, water resources and water pollution must be effectively managed and monitored to reduce anthropogenic impacts and their contributions to water pollution and the deterioration of water quality.

All the values of the studied physicochemical and biological parameters lie within the Jordanian and also the international standard (FAO) limits for irrigation, except the sodium concentrations in some dams, which surpassed the FAO standard limits for irrigation.

This study could provide helpful and worthwhile information for decision-makers to understand the current state of the dams' water quality and pollution for better and sustainable management of water resources, especially during acute water scarcity in Jordan.

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